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FINAL REPORT

THE STUDY AND EVALUATION OF ABSORPTION-BASED COOLING SYSTEMS FOR USE IN CIVIL DEFENSE SHELTERS

1 July 1964 to 31 July 1965

J. E. Ambrose
G. E. Commerford

SwRI Project 01-1580
Stanford B-70925 (4949A-10)-US
OCD-PS-64-201
OCD Work Unit No. 1425A

December 30, 1965

Prepared for

Civil Defense Technical Office
Stanford Research Institute
Menlo Park, California 94025

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SOUTHWEST RESEARCH INSTITUTE

SAN ANTONIO HOUSTON

Summary

of

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SUMMARY

This study is intended to evaluate the relative merits of various absorption cycle systems for cooling identified civil defense fall-out shelters which would impose a cooling load in the three to five-ton range. Some characteristics of a desirable system are: (1) equipment which will perform reliably and energy supplies (fuel) which will not deteriorate during extended periods of inactive storage; (2) simple and safe activation and operation; (3) electrical energy requirement no greater than that which can be generated from waste heat in the flue gas.

The work scope includes the study of problems associated with the use of absorption type package cooling units in various kinds of shelters, using various energy sources, with various means for rejecting heat. Comparison of various systems would determine the optimum solution or a compromise for further development.

The complete cooling system is composed of: (1) the absorption cycle cooling unit; (2) the shelter heat transfer unit; (3) means by which heat may be rejected from the cooling unit to a heat sink; (4) a fuel with its required combustion unit to provide the heat necessary to operate the cooling unit; (5) means by which fluids, such as air and water, may be moved through the various components; and (6) means of controlling the operation of the various components. The

package cooling unit should incorporate, insofar as practicable, the following characteristics: (1) be suitable for use in shelters and be compatible with one or more energy sources and heat rejection sinks; (2) be versatile and adaptible to various operational requirements; (3) be low in cost consistent with effectiveness; (4) be portable or capable of facile installation; (5) require minimum space; (6) be highly reliable and resistant to normal abuse; (7) have long standby life and resist deterioration under shelter storage environment; (8) have a nominal rated cooling capacity within the range of three to five tons; (9) require little or no electrical energy; and (10) be inherently stable for safe operation by untrained personnel with only simple instructions and guidance. Only commercially available components have been considered in the final evaluation. These units generally incorporate the characteristics listed above except Nos. 4 and 9 and perhaps 2. These are then compared on the basis of cost, electrical requirement, volume and weight.

The system which is most likely to be useful for shelter cooling appears to be the aqueous ammonia absorption cycle which incorporates direct rejection of heat to ambient air from finned-tube condenser and absorber. This is a water chilling unit, and the chilled water would be circulated through a finned-tube conditioning coil in the shelter. Shelter heat is removed by blowing shelter air and ventilation air through the conditioning coil. Heat to operate the absorption

unit would be supplied by combustion gases from a furnace designed to burn volatile-producing fuels with coal as the preferred fuel. Manual power would be used to pump the chilled water and circulate shelter air and cooling air.

Major developments required to complete this system are the design of a solid fuel furnace and the adaptation of the gas fired absorption unit to this furnace.

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APPROVED:

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December 30, 1965

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OCD REVIEW NOTICE

"This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense."

ABSTRACT

A study has been made of various absorption cycle cooling units and associated components which would be required to maintain a habitable atmosphere in certain identified civil defense fall-out shelters, independent of any external energy sources. Of the many criteria which could be applied to these systems, four were selected as the bases for the final evaluation, i.e., cost, electrical requirement, volume and weight. The selected system consists of the aqueous ammonia absorption cycle cooling unit with heat rejection directly to ambient air from finned-tube condenser and absorber. This unit produces chilled water which is circulated through a finned-tube conditioning coil within the shelter area. Shelter heat is transferred to the chilled water by blowing shelter air and ventilation air through the conditioning coil. Heat to operate the absorption unit is supplied by combustion gases from a furnace designed to burn a volatile-producing fuel with coal as the preferred fuel. Manual power is applied to pump the chilled water and to circulate shelter air and cooling air. A suitably designed furnace needs to be developed, and the normally gas-fired absorption unit must be adapted to the furnace.

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Major developments required to complete this system are the design of a solid fuel furnace and the adaptation of the gas fired absorption unit to this furnace.

II. INTRODUCTION

Civil Defense shelters located in high temperature, high humidity areas will require auxiliary cooling during the critical period of occupancy. The cooling provided by moving ambient air, adequate for many localities, will not provide an acceptable shelter environment with respect to health and personal comfort in others, e.g., southern portions of the United States during the summer months. During the critical period, energy sources normally used for providing artificial cooling will probably be limited or non-existent. Emergency supplies and equipment for this purpose will have to be available and usable.

Conventionally, artificial cooling is produced in a variety of ways using vapor compression machines, steam jet evaporators, absorption systems, etc. For the shelters of interest here, the cooling system is characterized by the relatively small refrigeration load (3 to 5 tons), by the need to use equipment and energy supplies which will perform reliably after extended storage, by its required simplicity and safety of activation and operation, and by a restricted electrical energy availability. The last assumes that the electrical supply is limited by storage or generation capacity. Because electricity must be stored or be produced from stored energy sources,

e.g., fuels, the direct utilization of thermal energy for artificial cooling should be of value for cooling civil defense shelters. Of the various cooling methods, absorption systems normally use thermal energy either directly from hot combustion gases or indirectly from steam. The fuels ordinarily used, e.g. natural gas, fuel oils, etc., possess characteristics which are not completely satisfactory for shelter storage or use - high degree of ignitability, significant storage pressure, uncertain storage life, etc. Solid fuels, such as coke, charcoal, coal, and others, appear attractive for this purpose, although ordinarily, little or no use is made of these fuels for cooling. These materials are relatively inert during storage, and their use and burning behavior are common knowledge.

The objective of this program was to study, evaluate, and select appropriate solid fuel - operated absorption systems which appear to be of value for use in civil defense shelters. Reduction of the shelter electrical load, improved fuel storage, and other benefits were considered to be probable where auxiliary cooling is required.

Other types of civil defense shelter cooling are of interest and are the subject of other OCD programs. Particular situations may be postulated in which electrical cooling will be preferred. Interest in the present study was restricted to characterizing absorption cooling systems operated with solid fuels. Modifications of other aspects

of conventional cooling equipment were considered and evaluated. For example, the heat to be rejected from absorption systems might be rejected to heat sinks of air, water, or earth; the normal practice is to reject heat to air or cooling water.

Absorption systems consume electrical energy for moving fluids, e.g. air blowers, chilled water pumps, and for instrumentation and controls. The substitution of manually developed energy sources, i.e., using the recently developed OCD-MRD bicycle drive for fluid moving equipment, results in very significant reductions in the electrical needs of absorption cooling systems.

Predictions of the probable length of shelter occupancy are difficult. For this study, the need for cooling was assumed to exist for two full weeks or 336 hours. While the reduction of the cooling load during the night is recognized, the variation of this load with different locales and seasons is uncertain. For this reason, the probably upper limit of isolated occupancy of two weeks was used as the basis for comparison.

III. TECHNICAL DISCUSSION

A. Background

Appropriate areas of some public buildings, e.g. basements, have been designated as identified civil defense shelters. The need for auxiliary cooling of these shelters under certain circumstances has been established. The cooling duty of three to five tons was expected to provide an environment conducive to survival during emergencies. Although broader limits with respect to personal comfort can be tolerated at these times, survival in certain locales was considered to be dependent on artificial cooling. The need for cooling will be expected to vary widely and be related to ambient conditions, to the number of occupants, and to the shelter location. The large number of identified shelters precluded the individual design of component systems specific for each shelter. By standardizing equipment size, significant benefits will result in the development of adequate protection for the largest number of people.

Absorption cooling systems operate by using thermal energy for vaporizing a refrigerant from an absorbing solution. The refrigerant vapor is condensed and cooled. Evaporation of the liquid refrigerant by environmental heat produces cooling. The vaporized refrigerant is reabsorbed and recycled for additional refrigerant vapor generation. The refrigerant-depleted absorbing solution,

subsequently cooled after refrigerant vapor generation, supplies the driving force for refrigernat evaporation during the cooling process. In the absence of this pressure differential, refrigerant vaporization and thus the cooling process would stop. Heat must be rejected from the refrigerant vapor condenser and from the refrigerant vapor absorber. Thermal energy is supplied to the absorption system during refrigerant vapor generation, and during liquid refrigerant vaporization, i.e., the cooling process. Absorption systems are characterized by their coefficient of performance (COP), which is defined as the number of Btu's of cooling produced per hour per number of Btu's per hour of available thermal energy in the fuel. This COP factor differs from that ordinarily used for vapor compression systems. For absorption systems, the COP factor is related to the thermal energy available in the fuel; for electrical systems, the inefficiencies of converting fuel energy to electrical energy are not included.

Common fuels used for absorption systems are natural gas, LPG, and fuel oil. The fuels are burned, and the thermal energy in the hot gases is used directly to vaporize the refrigerant from the absorbing solution. Low pressure steam is often used when available, especially in commercial situations. The rejection of heat from the absorption system depends on the working fluids. Heat is rejected to cooling water from lithium bromide systems, and to air from the

aqueous ammonia cycle. For conventional use, each has particular advantages. The use of cooling water with lithium bromide units yields a COP of 0.54, because heat rejection is to a sink at temperatures usually below ambient. The convenience of air for heat rejection from aqueous ammonia units is partly responsible for its lower COP of 0.3. Operation of the lithium bromide system at the same rejection temperatures as the aqueous ammonia results in similar COP's. Both of these systems are used for residential cooling in the three to five ton range.

A third type of absorption unit recently developed at SwRI is based on the so-called double effect lithium bromide cycle. Although a significant improvement in efficiency was obtained (COP = 0.75), its use for these relatively small sizes remains to be developed commercially.

During this study, the possible influence of so-called non-technical factors on artificial cooling system evaluation was recognized. A particular system may be technically sound but be of little practical interest here because of these considerations. For example, some cooling systems for identified shelters located in public buildings may require significant building modification which may be unacceptable for normal building use. The underlying assumption present in this study was that of finding the best technical solutions to the problem

within the guidelines of providing acceptable conditions for component storage and shelter operation. A simple example might be that bags of charcoal can be stored with reasonable safety without the need for specially-built storage facilities.

Commercially available absorption systems contain equipment for transferring the heat from the cooled area to the system, for rejecting heat from the system to appropriate sinks, for moving fluids such as chilled water or cooling water, for monitoring and controlling the system operation, and for utilizing the thermal energy from the combustion unit. The sealed nature of these absorption systems permits modifications to be made on the external equipment without disturbing the basic unit. In effect, these external units represent imputs and outputs to a "black box", i.e., the absorption system. It was recognized that the specifications of commercial absorption systems reflect their normal quaranteed life of five years of operation. Although these might exceed, perhaps greatly, the ultimate needs of this program, the possibility of cost-reducing modifications involving their sealed nature was deferred to a future effort. By demonstrating the feasibility of useful external modifications, additional efforts for those involving the sealed system might then be justified. If presently available absorption units cannot be adapted for a useful role in shelter cooling, the additional efforts appear superfluous.

The minimization of the electrical requirements was considered in terms of substituting either thermal or manual energy where appropriate. The total generation of electrical needs directly, as with thermoelectric elements, was not considered in this study. In the case of thermoelectric generation, the comparison should properly include alternate methods. The effect of such a comparison would broaden the scope of this study beyond its intended limits, since electricity may be required in other operations of the shelter. To consider thermoelectric generation for providing only the electrical needs of the absorption system will result in an unrealistic comparison. The inclusion of alternate methods of generating electricity to meet other shelter needs also expandes the cooling system evaluation to other cooling processes, e.g. electrically operated vapor compression systems. Thus, this study was limited to absorption systems because they operate directly on thermal energy, and to the minimization of electricity, preferably by substitution of manual or thermal energy. Any other electrical needs would have to be provided for within the overall operation of the shelter system.

B. Detailed Description of Shelter Cooling Components

1. Absorption System

a) Aqueous Ammonia Type

The Bryant Manufacturing Company, 2020 N. Montcalm, Indianapolis, Indiana, produces the only aqueous ammonia absorption system of interest in this study. In normal use, thermal energy is supplied by a gas burner. Heat is rejected to ambient air blown across finned absorber and condenser coils. This unit produces chilled water which circulates from the usual outdoor location of the absorption system to conditioning coils located within the area to be cooled. Apparently, the outside location is partly the result of regulations relating to the remote possibility of ammonia leakage. During normal operation, internal pressures are above atmospheric pressue. Because of the weight of these systems, they are not adaptable to extensive moving, and preinstallation is indicated.

This system uses water as the absorption medium and ammonia as the refrigerant. On heating the ammonia-water solution in the generator, gaseous ammonia is separated from the solution and liquefied in the condenser. This liquid refrigerant is vaporized by absorbing heat from the warmed water returning from the conditioning coils. The vaporized refrigerant is absorbed by the cooled, ammonia-depleted solution produced in the generator. The resulting ammonia-rich solution is reheated in the generator, thus completing the cycle.

In commercial units, the usual practice is to transfer heat from the hot ammonia-depleted solution leaving the generator to the cool ammonia-rich solution entering the generator to reduce the heat input required of the burner. Theoretically, high thermodynamic efficiencies are inherent in this cycle; practically however, the volatility of water and difficulties associated with complete separation of water and ammonia contribute to a much lower efficiency. A new unit is currently being field tested by RCA Whirlpool Corp. which is claimed to achieve a COP of 0.5. This unit weighs 565 lb. and measures 37" wide, 28" deep, and 36" high. Improvement of the Bryant unit is also expected in the future.

The Bryant unit is charged with the ammonia solution at the factory. The quantity of the charge is critical to efficient operation. Leakage from the unit is not likely except as a result of damage to the unit during shipping. These units have been operated for periods of 10 years without losing the original refrigerant charge. One instance was given by the local distributor of a unit which stood idle for 4 years and was restarted without difficulty.

The following table shows the pertinent data with respect to the only aqueous ammonia absorption system manufactured in sizes of interest in the shelter cooling program.

TABLE I

Specifications and Data of Bryant 3-Ton Aqueous Ammonia Absorption Unit *

Thermal Input to Generator	88,000 Btu per hr
Cooling Capacity	36,000 Btu per hr
Heat Rejection to	95°C ambient air
Chilled Water Temperature	50°C
Chilled Water Rate	7.5 gpm
Overall Weight of Unit	780 lbs
Overall Volume of Unit	43 cu ft
Overall Dimension of Unit	31"x46" floor space, 52" high
Electrical Requirements of Unit	600 watts
Cost of Unit	$900

* Bryant Model 36-451

Major areas susceptible to modification of this commercially available residential unit for shelter cooling are to -

1) change the thermal energy source from gas burning to solid fuel combustion,

2) provide for manual operation of fluid moving equipment in case electricity is limited or unavailable,

3) adapt the heat rejection coils for use with water or air-water combinations, in case electricity is unavailable, but adequate water is available, and

4) to alter electrically operated switches, instruments, controls, etc., to non-electrical operation, in case electricity is limited or unavailable.

Item (1) appears to be the most important modification, and the potential value of absorption cooling in shelters seems heavily dependent on usefully achieving this objective. Because this unit produces only chilled water, the method of transferring shelter heat to it will determine the extent of electrical saving. Normally, conditioning coils are used for this purpose. Chilled water circulates through externally finned tubes across which air to be conditioned is blown. Satisfactory substitution for the electrical operation of the fan and the chilled water pump will permit the commercially available conditioning coils to be used. Lacking this situation, other methods for transferring heat to the chilled water which minimize the electrical requirement will be needed. The use of water, if available, to minimize electrical energy needed for heat rejection also may be of value. For example, instead of blowing air across the condenser and absorber coils, the use of cooling water might permit the elimination of the blower electrical requirement. Similarly, alternate devices for monitoring and controlling the operation will probably be of value in addition to the now existent electrically operated instrumentation. Modifications of this equipment for emergency use should be readily adaptable to normal operation if electricity or conventional fuel are available.

b) Lithium Bromide Type

The Arkla Air Conditioning Company, 812 Main Street, Little Rock, Arkansas manufactures the only lithium bromide absorption units of possible value for shelter cooling. Thermal energy is supplied by fuel burners or by condensing low pressure steam. In the air conditioning versions of this system, air is cooled directly by its movement across finned tubes in which the water refrigerant is evaporated at low pressures (8-10 mm Hg absolute). Other units are used to produce chilled water for circulation to conditioning coils. These absorption systems are hermetically constructed because of the sub-atmospheric internal pressure present at all times.

Lithium bromide salt solutions serve as the absorption solution and water as the refrigerant. Water is vaporized from the lithium bromide solution in the generator, separated from the solution, and then condensed by cooling water. The liquid water refrigerant evaporates at low pressures maintained by the cooled, water-depleted lithium bromide absorption solution.

As water vapor is absorbed by the water-depleted absorption solution, the heats of solution and mixing are removed by external cooling water. To minimize the thermal energy input, the hot, water-depleted absorption solution leaving the generator is used to preheat the cool, water-rich solution entering the generator. Important to the proper operation of these systems is the use of pressure heads for

moving liquids through the unit thus eliminating the need for internal circulating pumps. The reliance on dripper troughs for the liquid distribution in the evaporator and the absorber requires leveling of the entire assembly for proper operation.

The combustion of fuel oil, LPG, and natural gas, or condensation of low pressure steam are the usual sources of the thermal energy for operation. Small amounts of hydrogen may be generated within the unit during operation in quantities sufficient to affect seriously the proper operation of the system. In normal operation, this gas is removed by diffusion through electrically heated palladium cells. The amount of gas involved and its removal does not present any difficulties for use in shelters.

Lithium bromide absorption systems are very reliable when properly installed and operated. These units are bulky and heavy, thus not adaptable to being moved, and preinstallation seems essential for proper operation. Because the internal pressure is below atmospheric at all time, they are extremely safe. The lithium bromide solution is corrosive, but its leakage is only a remote possibility. On rare occasions, crystallization of the solution may produce blockages which interupt the operation. High temperature alarms or other devises in lieu of presently used shut down switches will serve to alert operators of this situation.

Various combinations of fuel and methods of cooling are available commercially. Natural gas, LPG, fuel oil, and low pressure

steam may be used for thermal energy input. The direct-fired units differ primarily in the design of the burner required for a particular fuel. The steam-operated units employ a condensing jacket in place of a burner; thus, this generator design differs radically from that of the fuel operated units. Cooling may be provided by direct cooling of the air, i.e., air conditioning, or indirectly by chilled water production. The design of these evaporators also differs greatly. For air conditioning, the low heat transfer coefficient arising from the direct cooling of air by the internal evaporation of the water refrigerant necessitates a large heat transfer area which is provided by external fins; whereas, fins are not required on the water chiller tubes. Remotely located finned conditioning coils are often used with the water chiller. Commercial lithium bromide air conditioners and water chillers in these sizes generally include a heating system. Though this may add somewhat to costs and bulk, the adjustment of these parameters to reflect the omission of the heating unit is of little significance. These units are charged with lithium bromide solution at the factory. During storage some hydrogen may be generated in the unit and the unit might require pumping to restore the proper vacuum before starting operation.

The following Table (Table II) presents the pertinent information with respect to the lithium bromide system.

TABLE II

Specifications and Data of Arkla 3-Ton Lithium Bromide Absorption Units

	Air Conditioner *	Water Chiller **
Thermal Input to Generator - Btu per hr	63,000	62,000
Cooling Capacity - Btu per hr	36,600	36,600
Heat Rejection to	85°F cooling water	
Overall Weight - lbs	955	1,260
Overall Volume - cu ft	62	103
Overall Dimensions	26-1/4"x54-3/4" floor space 74" high	32"x84-1/4" floor space 65" high
Electrical Requirements - watts	500	950
Cost of Unit	$785	$1,100

* Arkla-Servel Model 501A

** Arkla-Servel Model 500C

Heat from lithium bromide absorption units is normally rejected to cooling water. If large and inexpensive quantities of water are available, a once-through system may be used. Ordinarily, a cooling tower serves to minimize water consumption. For shelter use, if otherwise unavailable, adequate water for cooling must be stored. For a three ton unit, about 100 lbs of water per hour must

be evaporated in the cooling tower to supply sufficient rejection capacity. For two weeks of full time operation, about 4000 gals of make-up water are required. This is in addition to any cooling water inventory and blowdown.

Elimination of the large volume of cooling water and the cooling tower may be possible by using air to cool the cooling water. Ambient air at 95°F would be used to cool finned coils through which cooling water is circulated. At the least, if such cooling could be accomplished, a significant decrease in cooling capacity of the absorption unit would result. At 95°F, the resulting capacity is estimated at about 60% of the nominal. To obtain 3 tons of cooling, using air at 95°F for heat rejection, a 5-ton unit is necessary. The assumption of lowering the cooling water temperature to 95°F by ambient air at that temperature is very optimistic. Large heat transfer areas will be required, even if the cooling water temperature were decreased to within two or three degrees of ambient temperature. Further decreases in capacity with eventual inoperation of this system occurs with higher cooling temperatures. It should be noted that a commercial lithium bromide unit from which heat is rejected to ambient air remains to be developed, although its value and convenience have long been evident. As the heat sink temperature

increases, the COP of the lithium bromide unit approaches that of the aqueous ammonia system, being about equal at 95°F. Thus, the advantage of a higher COP for lithium bromide unit disappears, even if its heat could be rejected conveniently to ambient temperatures.

In summary, if large quantities of cooling water are unavailable for heat rejection, operational advantages, such as decreased fuel consumption of the lithium bromide unit, disappear. As a practical consideration, the availability of large amounts of cooling water, as for example from underground sources, suggests that adequate auxiliary cooling might be possible directly with such water, rather than reliance on artificial refrigeration systems. The uncertainty of the availability of such water for shelter use eliminates its consideration for cooling the shelter directly or for heat rejec tion. However, if it should be available within the shelter, operation of a selected system should be sufficiently adaptable to take advantage of it.

Steam-operated units differ from fuel-operated ones in the design of the refrigerant generator. Because of the higher heat transfer coefficient with condensing steam, such generators are quite compact. Unless steam is available as a waste-product, for example from steam-driven equipment incorporated into the shelter assembly, a steam boiler is required. The need for this extra equipment appears

merely to complicate the shelter system with little advantage. The fuel would be used to generate steam in a boiler instead of refrigerant in the absorption system generator.

The modification of commercial lithium bromide units appears to be of little value, because of the limitations imposed by heat rejection. Although lithium bromide units possess some advantages such as no toxicity hazard, none of these seem sufficient to compensate for their disadvantages.

2. Components for Transferring Shelter Heat

a) Conditioning Coils

Ordinarily, air to be conditioned is blown across externally finned tube surfaces cooled internally by evaporating refrigerant or circulating chilled water. Lithium bromide units are available for using either method. The aqueous ammonia system produces only chilled water. The use of chilled water permits so-called split operation in which the conditioning coils are located remotely from the absorption system. A chilled water pump and a conditioning coil fan for air movement are necessary for this operation. The transfer of shelter heat directly to evaporating refrigerant may be accomplished by moving the warm air through the finned tube evaporator of an appropriate lithium bromide unit only. In this case, a blower serves for moving air through the evaporator and into the cooled area.

The easy handling of chilled water coils makes these highly adaptable to a variety of shelter configurations. Connections for the chilled water circuit can be relatively simple, e.g. flexible plastic or rubber hose with ordinary couplings. To adapt the air conditioner, the use of duct work is indicated, especially to distribute cooled air throughout the conditioned area. In addition to the location flexibility of chilled water coils, their reduced bulk compared to air ducts would seem to be an advantage during storage, installation, and perhaps during operation.

Because of their use in normal cooling operation, conditioning coils are well-defined with respect to pressure drops, horsepower requirements, heat transfer and the like. The following table (Table III) indicates the characteristics of typical coils in commercial use. Similar coils are available from other component manufacturers because of the wide commercial use of chilled water systems.

TABLE III

Specifications and Data for Conditioning Coils

Type - Finned Tube Coil	Bryant Model 36-405	Arkla-Servel Model FCF42-96A
Overall Dimensions	22"x33"x27-1/2"	20"x32-3/4"x36-7/8"
Overall Volume	11.5 cu ft	14 cu ft
Overall Weight	165 lbs	168 lbs
Water Inlet and Outlet	1" F.P.T.	1" F.P.T.
Air Inlet	20"x24-1/2"	
Air Outlet	14"x20"	
Blower Electric Requirements	350 watts	440 watts
Cost of Unit	$190	

b) Spray Tower Concepts

Another approach to transferring heat from the shelter air to a chilled water stream involves the direct contact of the air and the water. This concept utilizes equipment in which the surface area of the chilled water is increased considerably by spray, droplet, or mist formation, hence the name "spray tower". Although this technique has been used for cleaning gases and cooling high temperature gases, it does not appear to have been used in conjunction with air conditioning systems using chilled water. The main reason for this is probably the convenience of the conditioning coils, and the absence of any need to eliminate or minimize electrical requirement.

Conceptually, chilled water would be pumped to the top of a tower and descend in the form of droplets or spray. The air to be conditioned would pass counter- or cross wise to these deoplets. The contact of the warm moisture-laden shelter air with the chilled water droplets (50°F) would result in the cooling of the air and the condensation of some of its water vapor. The slowly increasing chilled water inventory, due to the condensation of about 5 to 10 lbs of water vapor per hour, might serve to supplement the shelter water supply. The main advantage of this concept is the possible reduction in the work required to move the air and water for transferring the heat. An obvious disadvantage is the need for air ducts.

A variety of designs may be of interest with respect to this concept. The volume of the tower, i.e., volume for adequate water-air contact, is related to the surface area of the water droplets. The use of packing, fill, drip surfaces, sprays, etc., decreases the tower volume but at the cost of increased work, i.e., pressure drop. Using data obtained experimentally for very much larger towers cooling much warmer gases, an estimated size for a tower filled with vertical boards was about 3 to 5 sq ft base area with a height of the order of 5 to 8 ft. The fluids must still be pumped; some work is required for water circulation, and the work for moving the air through

the tower was estimated to be about the same as across finned coils. Thus, although the size of this type of tower may be acceptable for shelter use, no significant decrease in the work input was found for this particular design.

The main problem in evaluating this concept in its numerous forms is the dearth of pertinent data obtained experimentally for specific designs. This need for experimental data seems to relegate this concept to some later period of development. Although it may have some future value for shelter cooling, the selection of the best tower configuration at this time seems highly speculative. The availability and applicability of the well characterized conditioning coils fulfill adequately the requirements for transferring shelter heat, providing the electrical input can be decreased or eliminated.

c) Curtain Concept

The sole purpose of presenting the curtain concept in this study is to show how shelters may possibly be cooled without mechanically moving the air. Entirely conceptual, this approach to transferring shelter heat is based on establishing cold surfaces within the shelter. For example, cloth curtains hung vertically might be kept saturated with chilled water. Heat transfer from occupants and the shelter surfaces would be mostly radiative and convective. Occupants

at body temperature would radiate heat to the wet curtains at chilled water temperatures of about 50° - 60°F. Convection currents would be set up by the cooling of the air in contact with the curtain. Condensation of shelter water vapor would also be expected. In this way, with sufficient curtain surface, the chilled water in the curtain would be warmed by the shelter heat.

Several techniques for keeping the curtain wet seem feasible. Immersion of the uppermost edge of the curtain in an elevated chilled water trough would cause downward water flow by wicking. Or, drippers from the elevated chilled water trough would cause water to descend on the curtain. Water flowing from the bottom of the curtain would be collected by a warm water return trough. Rough calculations using heat transfer coefficients of 1 and 0.5 Btu per hr per sq ft per °F, and temperature differences of 45°F and 20°F for the radiative and convective transfer mechanisms, respectively, yield a curtain size estimate of 10 ft by 33 ft, if both sides are used. Although the value for the heat transfer coefficients may be somewhat optimistic, the concept seems feasible. However, a serious limitation would be the psychological effect on the occupants of a cold, wet curtain in their midst, perhaps with incessant dripping noises. The chilled water would still have to be circulated from the lower trough through the chiller and raised to a gravity tank feeding the upper trough.

The lack of satisfactory data for designing such a system, the probably undesirable aspects of the wet curtain, and the availability of proven conditioning coils indicate that this concept is of little interest or value now.

3. Heat Sinks and Components for Heat Rejection

The heat sinks of interest in this study for the acceptance of heat rejected from the absorption unit are air, water, earth, and perhaps others.

a) Heat Rejection Direct to Air

As noted above, of the two basic absorption units considered, only the aqueous ammonia system rejects its heat directly to universally available air. While other sinks may have value in particular shelter situations, only air can be relied on in all identified shelters.

Heat is rejected from the aqueous ammonia unit to ambient air blown across finned condenser and absorber tubes. The resulting rise in air temperature necessitates discharging hot air outside of the shelter environment with subsequent replenishment by ambient air. For example, location of the absorption unit in a utility room adjacent to the shelter will require the discharge of the hot air from the utility room and an influx of ambient air. A portion of the

cooling air may be that originating in the shelter and which is to be discarded to maintain safe carbon dioxide levels. The aqueous ammonia unit is designed to use the cooling air blower for discharging flue gases with the hot air stream containing the rejected heat.

The use of air as a sink for rejecting heat directly from lithium bromide units is not feasible at the present time.

b) Heat Rejection Indirectly to Air

The indirect rejection of heat to air consists of using an intermediate heat transfer agent between the absorption unit and the air heat sink. A cooling tower for evaporating a portion of a circulating water stream warmed by rejected heat is an example of this method. To use the lithium bromide absorption unit which is dependent on water for heat rejection necessitates this approach. The main disadvantage here is that a large quantity of water must be available to supply the circulating and cooling tower inventory, the water evaporated, and the blowdown, if any. For two weeks of full time operation of the 3 ton unit, the makeup water to replace that evaporated is about 4000 gals. This does not include the inventories or blowdown requirements. The following table (Table IV) lists the characteristics of the cooling tower ordinarily used with the 3 ton lithium bromide absorption unit.

TABLE IV

Specifications and Data of the Arkla Evaporative Cooling Water Tower *

Heat Dissipation	105,000 Btu per hr
Water Circulation	12 gpm
Water Evaporated	12 gph
Overall Weight - dry	350 lbs
Overall Weight - operating	550 lbs
Overall Dimensions	28-1/8"x49-7/16" floor space 51-3/4" high
Overall Volume	42 cu ft
Total Electrical Requirements	
Fan and Circulating Pump	900 watts
Cost of Unit	$305

* Arkla-Servel Model TF-101K

Other heat transfer media, e.g. water or other liquids, may be considered for transferring absorption unit rejected heat to the air by sensible heat changes only. Because of the film heat transfer coefficient limitation on the air side, enormous surface areas will be required to reduce the liquid temperature to within a few degrees of the postulated 95°F ambient. Since the value of indirect heat rejection to air is limited to the lithium bromide system, the expected decrease in capacity must be considered, which at 95°F was estimated at 60% of

the rated capacity. Because rejected heat transfer media cannot be lowered practically to 95°F with 95°F ambient air, a still lower capaccity is certain. This requires the lithium bromide unit to be greatly oversized to provide the nominal 3 tons of cooling. Any fuel efficiency advantage of the lithium bromide system thus disappears. At 95°F, the COP's of both basic systems are identical, i.e., about 0.3

The indirect rejection of heat to air offers no advantage for use in shelter cooling. In the case of aqueous ammonia, direct rejection to air is preferred; for lithium bromide, the modifications to permit its operation yield no advantages when compared with the aqueous ammonia system.

c) Heat Rejection to Cooling Water

Adequate quantities of cooling water may be on hand during shelter occupancy. Sources such as streams or ponds, large storage tanks, or ground and well water supplies developed during occupancy, could simplify operation of the shelter cooling equipment. Ground sources such as wells might be able to provide sufficient cooling if curculated through conditioning coils in place of chilled water. Usually, the temperature of water available above ground in these locales might be expected to be too high for direct shelter cooling. In this case, the water might be used for cooling heat rejection surfaces by immersion, by falling films, by sprays, etc. The use of water for

this purpose may reduce or eliminate the energy required for blowing air through the finned condenser and absorber tubes of the aqueous ammonia unit. The modification of finned coils to use water appears to be of limited interest since the capability of rejection to air must exist. Appropriate modifications to use water, if available, appear straightforward but of marginal value in this case.

Because of the limited number of situations involving adequate quantities of cooling water, its substitution for air in shelter cooling systems does not appear justified. Although some benefit would result if provisions were made for this purpose, the primary dependence on air for heat rejection seems essential for most shelter situations.

d) Heat Rejection to the Earth and Other Sinks

Heat rejection to earth and to other sinks was also considered. In the case of earth, problems exist in the probable variation and uncertainty of soil properties which will affect the heat transfer efficiency and storage life of buried coil surfaces. Though appropriate systems can be designed, the need for an intermediate heat transfer agent is indicated. Although this concept has been used in a limited number of cases, no general predictions can be made with respect to reliability and efficiency after installation using available data.

This idea seems very attractive at first glance for heat rejection, but because of the above-mentioned uncertainties, the use of earth for shelter heat rejection appears to be of limited value, at best.

Similarly, other sinks, e.g. those involving the latent heats of appropriate materials, are limited in usefulness. Attempts to use these sinks results in more complicated shelter systems with no significant advantages.

4. Fuels and Combustion Units

Absorption units are normally heated by burning various hydrocarbon fuels, or by condensing steam. The generation of steam for the indirect firing of absorption units increases the complexity of the system, unless the steam is available as a by-product of another operation within the shelter, such as electrical generation. This situation is not considered here, because the operation of the cooling system is assumed to be largely independent of other functions for the purpose of this study.

Normally used hydrocarbon fuels are characterized by uncertain extended storage life and relatively high ignitability. Fuels such as natural gas and LPG require special storage containers. Others such as fuel oil, kerosene, or gasoline possess uncertain storage life which introduces the question of reliability after long

storage. Solid fuels, on the other hand, appear to be definitely useful for shelter operation of absorption systems, because these fuels may be stored with little hazard or change for long periods. Their use is widely familiar to shelter occupants who are probably unknowledgeable with respect to the more commonly used fuels normally burned with a minimum of human attention.

Several categories of solid fuels were considered - fuels which are primarily carbon, fuels which generate combustible volatiles by decomposition, and those classified here as special fuels.

a) Primarily Carbon Solid Fuels

Solid fuels which consist primarily of carbon are coke, charcoal, and perhaps anthracite coal. Of these, probably chacoal is the most widely used and most familiar to probable occupants of civil defense shelters. These materials are somewhat difficult to ignite and produce heat by oxidation of the carbon. Although some combustible gas is generated and burned, heat transfer from a burning bed of these fuels is largely by radiation. For the purpose of determining feasibility, bed size was estimated for a furnace using these fuels for the direct firing of the absorption unit. For an ideal radiating surface (fuel bed) at 1500°F and an ideal heated surface (absorption unit generator) at 150°F, the coefficient of heat transfer by radiation is estimated at about 18 Btu per hr per sq ft per °F.

The estimated fuel bed area is slightly less than four sq ft. If the efficiency of heat transfer to the generator with respect to the energy available in the coke or charcoal is assumed to be 70%, the burning of about 10 or 12 lbs per hr of fuel is needed. The grate or bed size of four sq ft provides sufficient capacity for burning this quantity of fuel. The best configuration of the furnace would probably be with the fuel bed parallel to the heated surface. Some combustion volume should be allowed for burning the combustible gases generated. Air would probably enter from below the grate and pass up through the fuel bed. Hot gases would impinge on the heated surface and probably exit by the stack presently used for flue gases. The furnace would probably be a steel box with a grate located so as to provide for variable air intake from below, with a door for manual fuel feeding, and with an arrangement for removing ashes. Thermal insulation of the furnace will probably be needed to minimize heat losses from the steel shell.

Fuels which are primarily carbon are safely stored in bags or containers easily handled manually. The cold ashes might be placed in the empty fuel containers. If containers are combustible, those not needed can be burned. Fuel ignition can be effected is several ways, for example, by using an igniter liquid.

The following table (Table V) lists the characteristics of the most improtant solid fuels composed primarily of carbon.

TABLE V

Characteristics and Data for Coke and Charcoal Fuels

	Coke	Charcoal
Heating Value - Btu	11-13,000	12-13,500
Bulk Density - lb per cu ft	30	33
Thermal Efficienty - % **	70 *	70 *
Unit Cost - cents per lb	2.25	3 *
Storage Characteristics	Both are stable, non-toxic, and relatively inert to accidental ignition.	
Packaging	Both readily stored in conveniently handled packages, e.g. 25 lb bags.	

* Estimated

** Estimate of heat transferred to absorption unit relative to heating value.

It should be noted that a furnace designed to burn charcoal or coke may not be directly usable with solid fuels which produce combustible volatiles. These latter require sufficient volume above the fuel bed to complete the combustion process for efficient utilization of thermal energy.

b) Solid Fuels Which Produce Combustible Volatiles

Another class of solid fuels which are familiar to most probable occupants of shelters are those which on heating produce combustible gases. Wood and coal are common examples of fuels which burn with visible flames above the fuel bed. Much of the thermal energy produced from fuel combustion is contained in this flame and is transferred by convection of the hot gases, direct flame impingement, and radiation. Sufficient energy transfer back to the fuel bed must be maintained to continue the generation of combustible gases. At some point in this process, the carbon residue will burn similarly to coke or charcoal. As additional wood or coal is introduced, a combination of these processes results - the production and burning of released combustible gases, and the oxidation of the carbon residue. Ample furnace volume above the fuel bed is essential for efficient combustion of the fuel gases before they leave the furnace. For large furnaces, a cubic foot of combustion volume is provided for energy releases of 25,000 Btu per hr or more. Assuming a heating value for coal of 12,000 Btu per lb and a thermal efficiency of 75%, about 10-12 lbs of coal per hr must be burned to operate the absorption unit, i.e., the input to the generator of 90,000 But per hr. The heat release of burning 10-12 lbs of coal per hr is apprximately 120-140,000 Btu per hr. Using the value of 25,000 But per hr per cu ft of combustion

volume, the estimated furnace volume is 5 to 6 cu ft. A grate size corresponding to 10 lbs of coal per sq ft per hr results in a fuel bed of less than 2 sq ft. An estimated size of a furnace for burning volatile-producing fuels would be very roughly a steel box one and one-half feet square and two or three feet high above the fuel grate. Space below the grate must be allowed for ash collection and air intake. Thermal insulation of the furnace is indicated to minimize furnace wall losses. These estimates were for the purpose of determining the feasibility of using this type of fuel for operating absorption units. Although these estimates are subject to considerable uncertainty, the order of the estimated size appears to be compatible with the shelter requirements. Essentially, the size and shape is not unlike conventional coal- or wood-burning furnaces used for home heating.

For furnaces of this size and shape, the absorption system generator may have to be elevated to position its heated surface appropriate to the fuel bed. A detailed design of this furnace may indicate other configurations are preferred.

Tabl . presents the characteristics for the two most common volatile producing fuels, i.e., wood and coal.

TABLE VI

Characteristics and Data for Wood and Coal Fuels

	Wood	Coal
Heating Value - Btu per lb	5,000 *	12-14,000
Bulk Density - lb per cu ft	32	52
Thermal Efficienty - % **	60	75
Unit Cost - cents per lb	0.6	0.9
Storage Characteristics	Both reasonable safe and stable in absence of ignition sources. Coal known to release small amounts of combustible gases in open storage.	
Packaging	Both readily stored in conveniently handled packages. However, wood probably better used in standard lengths, e.g. 24" long.	

* Approximate value for oak.

** Estimate of heat transferred to absorption unit relative to heating value.

c) Special Fuels

Special fuels were defined here to include such diverse materials as paraffin wax, producer gas (generated from solid fuels), wax-coke or charcoal combinations, and gelled liquid fuels. Except for producer gas, too little definitive data exist for these to be of significant interest in the present study.

Paraffin or petroleum waxes appear sufficiently attractive for shelter use to warrant experimental in vestigation. These materials are completely safe with respect to toxicity, relatively inert to ignition, capable of being stored with minimum space requirement, and are familiar to most shelter occupants. They possess high heating values per weight (20,000 Btu per lb), and storage is unlikely to alter their utility. Their present disadvantage is insufficient information with respect to their burning behavior and combustion unit design. Table VII lists data for a typical paraffin wax.

TABLE VII

Data For Typical Paraffin Wax

Heating Value - Btu per lb	20,000 *
Bulk Density - lb per cu ft	45 *
Thermal Efficienty - % **	60
Unit Cost - cents per lb	6 *
Storage Characteristics	Reasonably safe and stable in absence of heat or ignition sources.
Packaging	Readily stored in easily handled packaged blocks or slabs. Packages adaptable for minimum storage volume.

* Estimated

** Estimate of heat transferred to absorption unit relative to heating value based on wick-type burning. Improved burner design may increase this value to about 75%.

The burning of wax candles for illumination is well known. This process produces light by virtue of the poor combustion which occurs as a result of slow fuel vapor generation at the wick. The laminar fuel flow limits the rate at which air is entrained by the flame envelope. Ordinarily, air enters the candle flame by diffusion with the result of incomplete combustion. Other fuels, such as wood, may generate combustible gases at rates which induce turbulent mixing of the gases and the surrounding air, thus causing the combustion to be more complete. The use of fuels which burn laminarly would be expected to be thermally inefficient. The accompanying deposition of unburned carbon may also contribute to poor heat transfer. To improve the combustion process, atomization, premixing with air, or other techniques are indicated. More air must be introduced into the flame than is possible with wicks dependent on capillary fuel vapor generation. At least two basic concepts of possible value to achieve this are visualized. First, an appropriately designed tray burner containing a multiplicity of vertical air intakes through the bottom of the tray and which are surrounded by molten wax might result in the turbulent evolution of combustible vapor by virtue of adequate back radiation to the liquid fuel surface. The array of air intakes would be such as to distribute the air throughout the fuel

gas volume more uniformly. Second, using waste heat to liquefy the wax and with an appropriate system design, the fuel entering the burner would be heated sufficiently for fuel vaporization. Proper burner orifice size might then produce the turbulent emergence of the fuel vapor, increased air entrainment, and improved combustion efficiency. Although both of these concepts are probably not new, the validity of their application for burning paraffin wax is uncertain and remains to be determined.

Mixtures of wax and other fuels may be of future interest, especially with fuels such as coke or charcoal. These are porous materials, not readily ignited and somewhat wasteful of storage space. By filling the voids even partially with wax, these and other characteristics will probably be improved. Although the resulting combinations might be similar to wood or coal, i.e., volatile producing, their burning behavior would be expected to be more uniform. However, their actual burning behavior is unknown and must be determined experimentally. For example, it may be that some of the wax contained in these fuels will simply melt and perhaps be lost to the burning process, or create a fire hazard. Little information is available for other fuels in this class, such as gelled fuels. While potentially attractive, their storage behavior after the probable extended periods of interest in this program is unknown.

Producer gas generation was considered because of its war-time use in place of gasoline for vehicle operation. Apparently, a large number of carbon-containing solid fuels, e.g. coke, charcoal, wood, baggasse, etc., can be and were used. Air and often also steam are passed through the hot fuel bed to produce carbon monoxide and some hydrogen. The gaseous products are a low Btu fuel which might be burned to provide heating. In addition to its low heating value, a serious disadvantage of this system for shelter use is that related to the toxicity of carbon monoxide. Although the system can be designed to minimize this hazard in shelters, the probable dependence on relatively unskilled assemblers and operators strongly indicates the need for avoiding this possibility. Also, the conversion of solid fuel to a fuel gas seems less attractive than the direct utilization of the solid fuel for operating the absorption unit.

5. Reduction or Elimination of Electrical Requirements

Electrical energy may not be available within civil defense shelters in amounts sufficient to operate conventional equipment. Electricity is ordinarily used for air and water moving, for instruments and controls, for lights, etc. For shelter operation independent of external energy sources, the minimization of the electrical requirement is essential. The substitution of thermally operated absorption cooling for the electrical systems in these sizes constitutes a significant electrical saving, i.e., 4 kw. Special circumstances may exist

during shelter occupancy which result in the availability of externally generated electricity, of fuel gas, or of large quantities of cooling water. Modifications providing for emergency, isolated operation should be readily adaptable to permit their use. However, the limiting situation under consideration assumes that these external sources are non-existent or of unspecified duration, and reliance must be placed on alternates for electricity where possible. Reduction or elimination of electrical motor requirements will decrease further the need to generate electricity specifically for the absorption system. For instruments and controls, either stored sources or thermoelectric generation, will probably be adequate, even if alternate non-electrical operation of these is not feasible.

The substitution of mechanical drives for electric motor-driven fluid-moving equipment was considered. One approach was to consider the substitution of fluid-operated motors, e.g. air or gas motors, water turbines, etc., for the electrical motors. These are not of particular value, because they require a driving force, such as compressed air, steam, elevation, etc. The availability of such a driving force suggests the possibility of generating electricity directly in place of the usually expensive and inefficient fluid-operated motors. If such a pressure source were available as a part of other shelter functions, its use for the cooling system could be evaluated. However,

the consideration of a special high pressure source for shelter cooling purposes by means such as direct fired boiler or engine driven compressor extends the range of this study to encompass all aspects of the shelter. In any case, it would appear that of the alternate uses for the pressure source, i.e., for fluid motors or electrical generation, the latter will be preferred because of cost, convenience, and other uses for the generated electricity.

Another approach to driving fluid-moving equipment might be to utilize the available human power within the shelter. Although a variety of devices or designs have been suggested and some evaluated, the bicycle-drive system recently developed by OCD-MRD may be of value for this purpose. Essentially, these pedal-operated devices convert human effort into shaft energy for driving pumps and blowers. Modifications of the pumps, fans, and blowers may be necessary because of the limitations imposed by man-power. These bicycle drives are available in sizes up to 0.3 hp in 0.1 hp increments.

Commercial cooling equipment is generally designed to meet a wide variety of situations. For example, to overcome pressure losses existing in relatively long residential ducts or lines, presently used blowers or pumps may be somewhat oversized for application in less demanding situations such as may exist or be acceptable in

shelters. More realistic equipment size and appropriate changes in driving arrangements for alternate electrical or manual operation appears quite feasible.

The use of thermoelectric elements for the total absorption system electrical load is of little value. In addition to the need for converting either the load or the electrical output, the high initial cost and low efficiency of thermoelectric elements render these unattractive for this purpose. For example, the generation of one kilowatt or 3413 Btu per hr with an efficiency of 3% requires approximately the same quantity of fuel as will be used by the absorption unit for cooling, i.e., about 100,000 Btu per hr from fuel combustion. Conventional generation is much lower in cost and more efficient. However, for supplying the small amount of electricity that might be needed to operate the instruments and controls, the use of a few thermoelectric elements operated by the waste heat in flue gases is feasible. The amount of thermal energy available in the waste heat was estimated to be about that which was needed by thermoelectric elements for supplying this relatively small load, i.e., about 100 watts or less. Since the instruments and controls consume but a small fraction of the conventional electrical requirements, the major problem in minimizing electrical needs of thermally operated absorption systems consists of providing alternate methods of driving the fluid-moving equipment.

The consideration of fuel cells, engine-driven generators, and similar equipment for producing electricity at the kilowatt level was not included in this study.

6. Miscellaneous Components

The major components of thermally operated absorption cooling systems were described above. Important to the proper operation of such systems during occupancy are a multitude of items which depend on the particular combinations of components selected. Among these items may be flexible plastic pipe or hose for distributing chilled water to the conditioning coils within the shelter. Appropriate coupling fittings for connecting the water lines, air ducts for separating hot air containing rejected heat from ambient air, flues or stacks for venting combustion products, fuel igniters, small shovels for handling fuel and ashes, hand tools for completing the cooling system assembly, and others. Clear, simple directions are necessary for proper assembly, activation, and operation of the selected and stored system by probably unskilled individuals. The detailing of particular tasks and division of labor for this purpose is probably appropriate. The use of color codes for hoses, couplings, indicating instruments, etc., in addition to non-interchangeable provisions should simplify the procedure and prevent improper installation. Indicating instruments which

are graduated in well known units and in coded color ranges may be of value; for example, a red danger zone may be marked in conjunction with temperatures above a designated value. Recognition of the existence of improper operating conditions would then not be dependent on the understanding of the measurements indicated by the units. Complete reliance on the availability of trained personnel can be minimized by these procedures. Although these miscellaneous items are important for cooling shelters, factors with respect to their cost, weight, volume, etc., were not included. The major components seem to be more important in this study. Each selected system will probably include some of these smaller items, although their particular form may very.

7. Summary of Components

The preceding discussion presented many of the advantages and disadvantages of components of interest in the absorption cooling of shelters. These components were:

a) Absorption systems,

b) Components for transferring shelter heat,

c) Components for rejecting heat and heat sinks,

d) Fuels and combustion units, and

e) Substitutes for electric motors and controls

The purpose of the following brief summary is to emphasize in a qualitative manner the apparent potential usefulness of the components previously discussed.

Of the two basic absorption systems, lithium bromide and aqueous ammonia, the latter appears to be the better unit for shelter cooling. Accepting the universal availability of air as the heat sink, the inability of adapting the lithium bromide unit without considerable extra equipment for heat rejection to air imposes severe limitations on the potential applicability of this system for shelters. At comparable sink or rejection temperatures, the similarity of COP's for both supports the attractiveness of the aqueous ammonia unit for shelter cooling. Neither has been operated commercially with solid fuels. The lithium bromide system is available as an air conditioner or water chiller, but the split operation of water chillers seems of more value here. The use of conditioning coils is indicated, because these are simple, easily installed, and convenient. If sufficient quantities of cooling water are available, relatively minor modifications in the operation of the coils normally rejecting heat to air seem feasible. A probable saving of work required to move the cooling (heat rejection) air would result. The uncertainty and variation of the earth heat sink behavior as well as other disadvantages eliminate its consideration for general use with absorption systems. Both volatile-producing and carbon solid fuels appear of value. A furnace adaptable for use with both of these classes of fuel might be possible and be of value.

For example, a simple steel insert might be used to convert the carbon fuel furnace for fuels such as coal or wood, which require much larger combustion volumes. Design and equipment tests may show that one furnace type will suffice for both types of fuel. Other fuels such as wax-charcoal combinations must be studied experimentally to determine their value for use in shelters. Alternates to electrical motors and minimization of the electrical energy requirements are indicated. If sufficient electricity is available, either generated withing the shelter or from outside source, more realistic fluid equipment sizing would probably reduce the amount required. By providing a system adaptable to manual energy inputs, such as bicycle-powered drives as an alternate, the electrical requirement for absorption cooling is decreased significantly. The electrical requirements of instruments and controls constitute a relatively minor portion of the total electrical absorption cooling load.

C. Criteria for Component and System Evaluation

The selection of potentially useful combinations of components for the absorption cooling of civil defense shelters will be based on the optimization of criteria important to the storage, assembly, and operation of selected combinations. Obvious factors, such as cost,

volume, weight, and electrical requirements will be totaled for each combination from actual or estimated information. The coincidence of each criterion optimum for one system is not expected. By ranking these criteria and using other less definable considerations, e.g. safety, skills required for operation or assembly, extent of pre-installation, etc., the optimum system should be evident. Some concepts and components appear quite obviously to be of little value in the cooling of civil defense shelters, aside from these factors or considerations.

1. Cost Criterion

The cost for absorption cooling systems will consist of the initial purchase price of the unit and its components. For commercially available items, the price quoted for retail purchase is used. Operating costs will not exist for these systems, because these are expended initially. Expense related to storage, space values, pre-installation and packaging are not included, since these may vary widely according to particular situations. Inspection and maintenence costs are also ignored here, primarily because these are related to the complete shelter system. Although the lowest total cost for the shelter will be of great significance, other criteria will exert an influence on this evaluation and selection.

2. Volume Criterion

Information with respect to space requirements are important both during storage and during the active phase. In this analysis, a total volume value is obtained by adding the individual volumes of the major components. It should be noted that a minimum total volume for a particular cooling system is not necessarily the minimum packaged volume for storage. A detained analysis with respect to minimizing the storage volume will probably show that one component might occupy voids within another. At this time, the emphasis seems to be more appropriately placed on potentially useful absorption cooling systems for shelter use.

3. Weight Criterion

Absorption systems are characteristically heavy and not conveniently handled or moved, even by several people. This heavy assembly results from the efforts of manufacturers to minimize field problems associated with installation and leakage of the sealed system. The elimination of similar difficulties seems even more important if used for shelter cooling. Here, sufficient time or skill may not be available for leak testing and assembling sub-components of the absorption unit. The present weight was accepted as is, and appropriate modifications or adaptations for shelter use indicated, e.g.

pre-installation, skids, wheels, etc. Fuel can be packaged in easily handled sizes. Other components appear to be adaptable for subdivision into convenient pieces. The weight criterion is of interest with respect to portability and installation of the components.

4. Electrical Requirements

The minimization of electrical requirements is of extreme importance in this study. Although the possible oversizing of commercial equipment and the substitution of manual effort for fluid moving is recognized, electrical inputs designated by the manufacturers for commercial versions were used for comparison. These values serve as guides for determining the feasibility of manual drive substitution for appropriate equipment.

5. Activation and Operational Considerations

A large number of this type of non-numerical criteria can be tabulated; some of these are hazards during storage, assembly and operation, amount of training or skill required for assembly and operation, extent to which system can be adapted for more favorable operating conditions than those assumed as limits, e.g. electricity or fuel gas being available, the degree of pre-installation, adaptability to a wide varity of shelter locations, and others. These considerations cannot be expressed satisfactorily as numbers, but rather qualitative evaluations must be used. Where a particular

consideration appears to be negative for an otherwise optimum system, e.g. the need for pre-installation, appropriate modifications to eliminate or minimize it will be required. Using these criteria as guidelines rather than excluding factors should result in a satisfactory selection, unless a particular criterion is such that it negates completely the other positive aspects of a system.

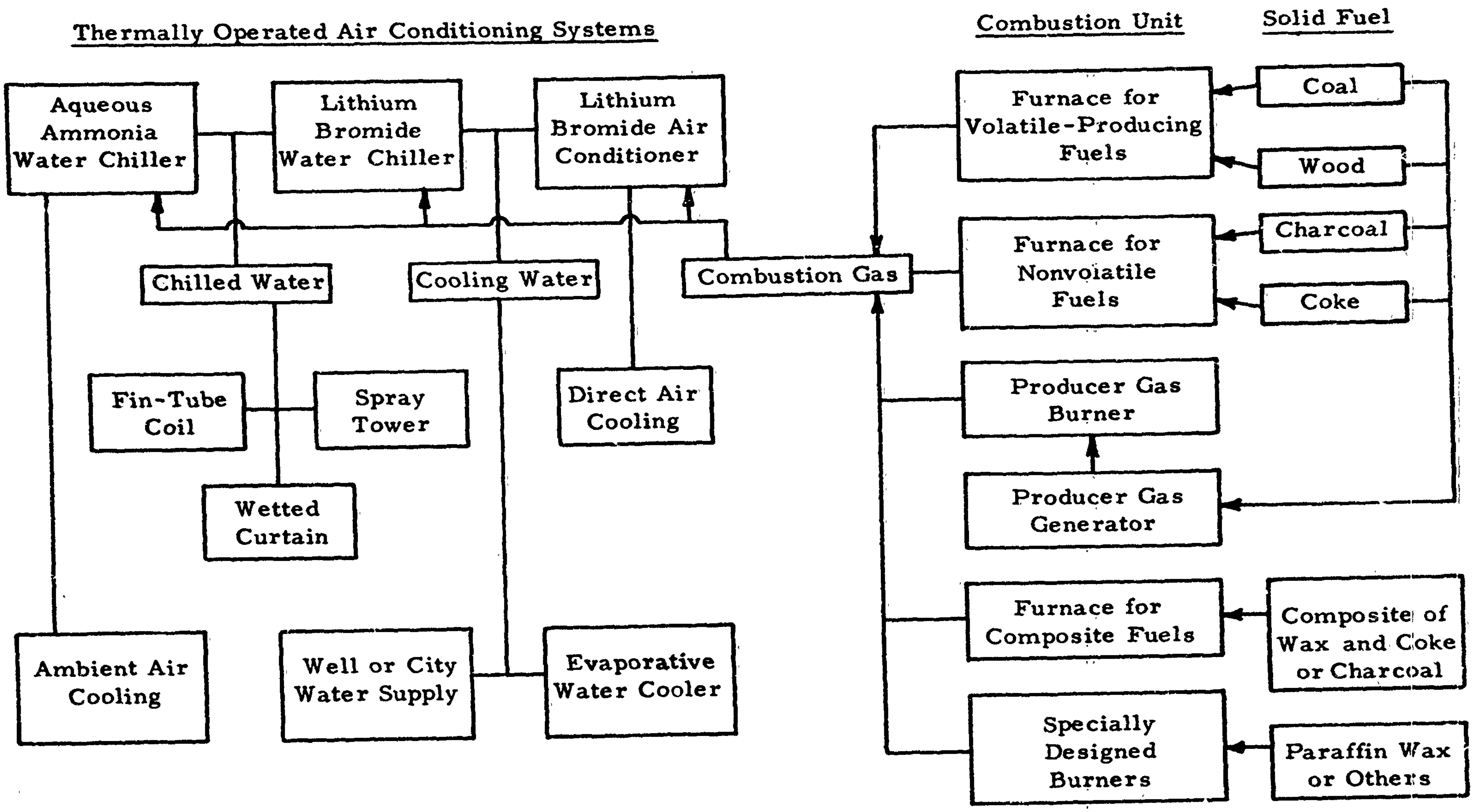
No attempt was made in this study to evaluate in any precise way the role of so-called non-technical factors. Examples of these are fire regulations, municipal codes, insurance restrictions, the need for building modifications, etc. Some aspects of these are contained in those listed above, e.g. the need for safe storage and operation. However, during this work, the emphasis was on reasonable safety, minimum building modifications, and similar points. The system was to be as potentially safe, reliable, simple, operable, and conveniently usable as was consistent with reasonable limits.

D. Evaluation of Systems

A large number of systems or component combinations appear to be capable of providing shelter cooling obtained from solid fuel-operated absorption units. A schematic representation of these is shown in Figure 1.

FIGURE 1

PROBABLY OPERABLE ABSORPTION-BASED SHELTER COOLING SYSTEMS



Components of each functional category connected by arrows form systems which would probably fulfill the requirements. However, the initial conditions to be met may vary greatly. Some of the components shown were found to be of little value. For example, systems using wax as the thermal energy source lack sufficient characterization for realistic estimates. Although apparently possessing valuable attributes for shelter cooling systems, the need for wax burner experimental data renders the consideration of wax impossible at this time.

The more than one hundred possible systems shown in Figure 1 were reduced to the twenty given in Figure 2 by imposing restrictions of the type just cited. Lithium bromide systems were included here in spite of their inability to reject heat to ambient air conveniently. Shelter situations may exist in which adequate quantities of cooling water are available. Also, the numerical evaluation of both basic absorption cooling systems commercially available seems appropriate.

A system number was devised for identifying specific combinations of components shown in Figure 2. Each component was assigned a code number (Table VIII); the system number was obtained by adding the code numbers of each component performing one of the five functions shown. The following example illustrated the use of these code and system numbers.

FIGURE 2

OPERABLE ABSORPTION-BASED SHELTER COOLING SYSTEMS

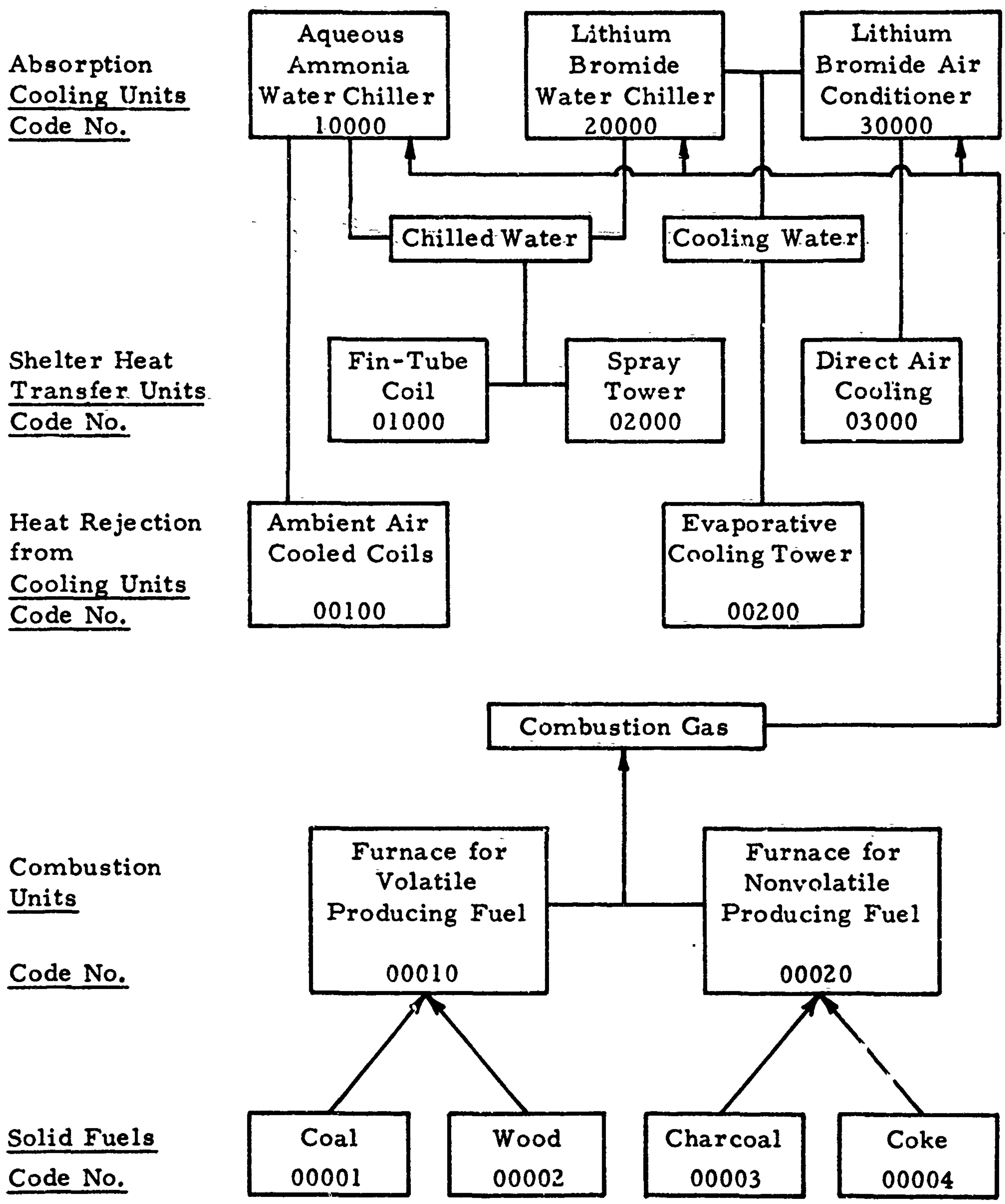


TABLE VIII

Component Codes

Function	Major Component	Code No.
Absorption cooling unit	Aqueous ammonia water chiller	10000
	Lithium bromide water chiller	20000
	Lithium bromide air conditioner	30000
Shelter Heat transfer unit	Finned tube conditioning coil	01000
	Spray tower concept	02000
	Direct air cooling unit	03000
Unit for rejecting heat from absorption system	Coils for use with ambient air	00100
	Evaporative cooling water tower	00200
Combustion unit for solid fuel	Volatile-producing fuel furnace	00010
	Non-volatile fuel furnace	00020
Solid Fuel	Coal	00001
	Wood	00002
	Charcoal	00003
	Coke	00004

System No. Digit Order	Function	Component	Code No.
1	Absorption cooling	Aq. ammonia unit	10000
2	Shelter heat transfer	Finned tube cond. coil	01000
3	Heat rejection	Air finned tube coil	00100
4	Combustion	Volatile-producing fuel furnace	00010
5	Fuel	Coal	00001
		System Number	11111

In some cases, a particular component restricted the use of other components. Thus, not all combinations of components are possible. This situation is shown by adjoining components which are not connected by arrows in Figure 2.

Four criteria were tabulated for each component assembled into a particular system - cost, volume, weight, and electrical requirements. As discussed previously, the total cost is important with respect to cost effectiveness, total volume with respect to storage and operating space requirements, total weight with respect to manual handling, and total electrical requirements with respect to manual drive or other electrical substitutes. Minimization of these would be expected to result in optimum systems provided the non-numerical criteria were satisfied.

A typical combination of components is shown in Figure 3. Tabulations of criteria values for each component are presented in Tables 1, 2, 3, and 4, in the Appendix. The system totals for each of the four criteria are listed in Table IX. Rank values were assigned for each criteria, but these were somewhat arbitrary. For example, a difference of $10 or $20 in the total cost of a system is probably not significant; therefore, each rank covers a range of values. For those systems using stored water, no criteria reflecting this are included.

FIGURE 3

FIGURE 3

TYPICAL COMBINATION OF COMPONENTS FOR SHELTER COOLING

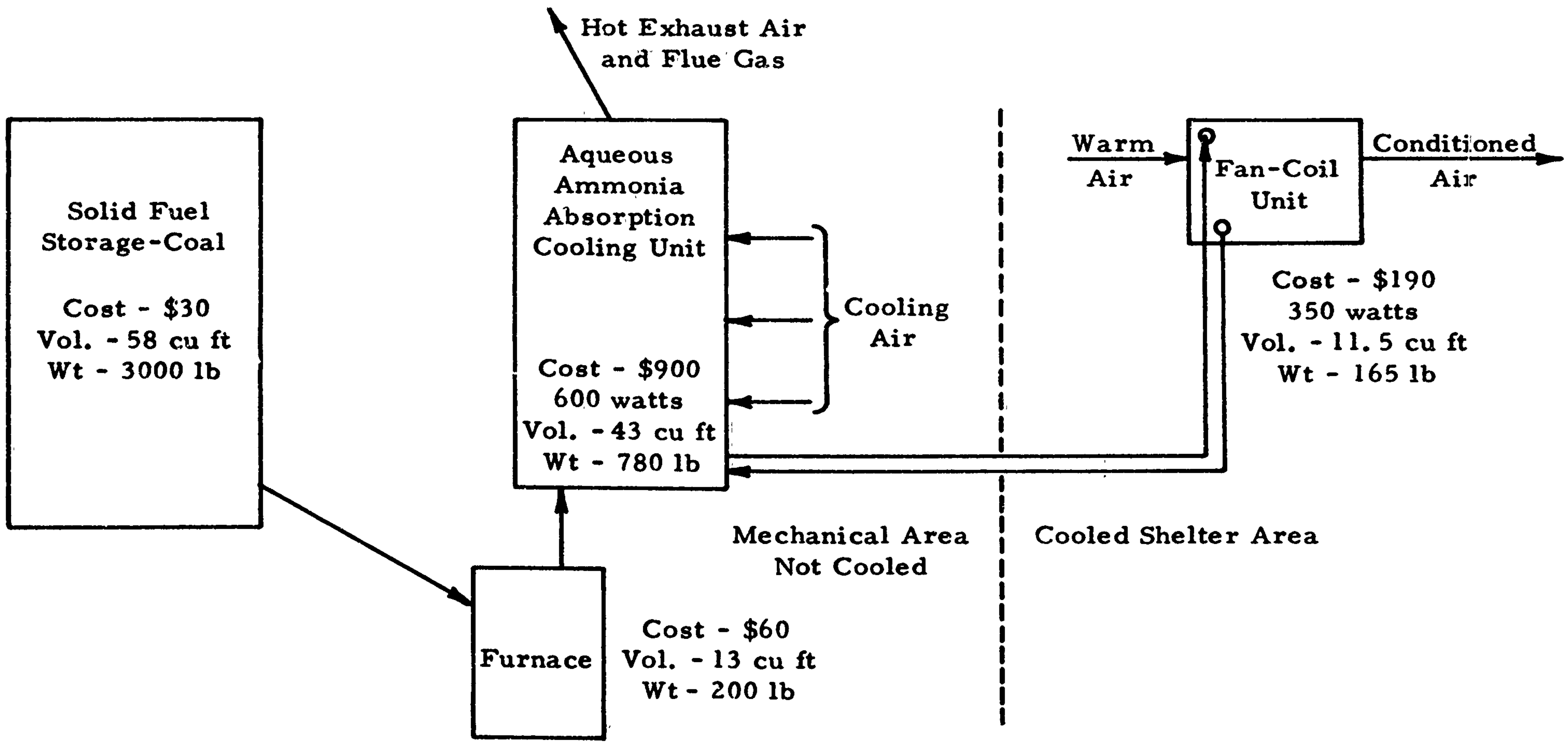


TABLE IX

Total Criteria Values for Each System

System	Total Cost	Cost Rank	Total Electrical Requirements	Electrical Rank	Total Volume	Volume Rank	Total Weight	Weight Rank
11111	$1180	1	950 watts	1	126 cu ft	1	4145 lb	2
11112	$1200	1	"	"	324 "	4	9145 "	4
11123	$1250	2	"	"	165 "	2	4445 "	2
11124	$1190	1	"	"	198 "	2	5145 "	4
12111	$1290	2	1040 watts	2	156 cu ft	2	4330 lb	2
12112	$1310	3	"	"	354 "	4	9330 "	4
12123	$1360	3	"	"	195 "	2	4630 "	3
12124	$1300	2	"	"	228 "	3	5330 "	4
21211	$1370	3	1390 watts	3	168 cu ft	2	3625 lb	1
21212	$1400	3	"	"	386 "	4	9625 "	4
21223	$1420	4	"	"	197 "	2	3925 "	1
21224	$1380	3	"	"	227 "	3	4625 "	3
22211	$1480	4	1390 watts	3	196 cu ft	2	3810 lb	1
22212	$1510	4	"	"	414 "	4	9810 "	4
22223	$1530	4	"	"	225 "	3	4110 "	2
22224	$1490	4	"	"	255 "	4	4810 "	3
33211	$1170	1	1400 watts	4	155 cu ft	2	3505 lb	1
33212	$1200	1	"	"	373 "	4	9505 "	4
33323	$1220	2	"	"	184 "	2	3805 "	1
33224	$1180	1	"	"	214 "	3	4505 "	3

The aqueous ammonia absorption systems using finned tube coils for transferring shelter heat (11000) are almost the same in total cost and the lithium bromide air conditioners (33000), which are only $10 to $30 lower in cost.

With respect to electrical requirements which are a measure of the need for manual or other drive substitution, the aqueous ammonia systems (10000) possess a clear cut superiority.

The aqueous ammonia absorption unit with finned-tube conditioning coils using coal as fuel results in the lowest total volume. The calculation of fuel requirement adjusts the quantity of coal, charcoal, and coke to reflect the difference in heat input to the three absorption units, since these fuels would probably be packaged for storage in a shelter, and fuel quantities could be easily adjusted. However, since fire wood is sold by the cord and varies in heating value and weight per cord, a set quantity of two cords has been specified for all component systems. This gives a volume of 256 cu ft and an approximate weight of 8,000 lbs for the fuel only. These values are 2 and 4 times the volume and weight of all other components in any given system.

Lithium bromide absorption systems (20000 and 30000) are lowest in total weight. However, the stored cooling water and tankage were not included in this evaluation, because their use will probably

be restricted to situations with assured water supplies. Inclusion of criteria values reflecting the need for stored cooling water would add approximately 30,000 lbs to the lithium bromide systems.

Similarly, a chilled water inventory is needed for the aqueous ammonia systems for the water chiller circuit, but this is much more modest and will not influence the system selection. This is also required for the lithium bromide water chiller system (20000).

The inability to use air for direct heat rejection was found to limit severely the value of the lithium bromide systems. Also, the use of wood fuel contributed to significant increases in the total volume and weight of such systems over those based on coal, charcoal, and coke.

Compared on the basis of equal weight for each of the four criteria, the optimum systems would be aqueous ammonia absorption units, transferring shelter heat using finned tube coils and directly rejecting heat to ambient air. Coal would be the preferred fuel. However, it is believed that these criteria are not of equal weight. The criteria have been ranked as follows: 1) cost; 2) electrical requirements; 3) volume; and 4) weight. The following equation is used to obtain a weighted average rank for each system:

$$\text{Wt. Ave. Rank} = \frac{4(\text{Cost Rank}) + 3(\text{Elect. Req. Rank}) + 2(\text{Vol. Rank}) + 1(\text{Wt. Rank})}{10}$$

These values are given in Table X. This method of comparison confirms the superiority of the aqueous ammonia absorption unit with finned-tube conditioning coils and using coal as fuel over all other combinations considered. It also indicates a slight advantage for the aqueous ammonia unit with finned-tube conditioning coils with other fuels including wood over the lithium bromide absorption units.

TABLE X

Weighted Average Rank of Component Systems

System Code No.	Total Cost Rank	Total Cost x4	Electrical Load Rank	Electrical Load x3	Total Volume Rank	Total Volume x2	Total Weight Rank	Total Weight x1	Weighted Average Rank
11111	1	4	1	3	1	2	2	2	1.1
11112	1	4	1	3	4	8	4	4	1.9
11123	2	8	1	3	2	4	2	2	1.7
11124	1	4	1	3	2	4	4	4	1.5
12111	2	8	2	6	2	4	2	2	2.0
12112	3	12	2	6	4	8	4	4	3.0
12123	3	12	2	6	2	4	3	3	2.5
12124	2	8	2	6	3	6	4	4	2.4
21211	3	12	3	9	2	4	1	1	2.6
21212	3	12	3	9	4	8	4	4	3.3
21223	4	16	3	9	2	4	1	1	3.0
21224	3	12	3	9	3	6	3	3	3.0
22211	4	16	3	9	2	4	1	1	3.0
22212	4	16	3	9	4	8	4	4	3.7
22223	4	16	3	9	3	6	2	2	3.3
22224	4	16	3	9	4	8	3	3	3.6
33211	1	4	4	12	2	4	1	1	2.1
33212	1	4	4	12	4	8	4	4	2.6
33223	2	8	4	12	2	4	1	1	2.5
33224	1	4	4	12	3	6	3	3	2.5

IV. OPTIMUM SYSTEM

The optumum system for the purpose of this program is found to be the aqueous ammonia absorption unit operated with coal (Figure 3). The use of circulating chilled water through a finned-tube conditioning coil is preferred for transfer of shelter heat. Finned-tube coils integral to the basic absorption unit are indicated for rejecting heat to ambient air. The low electrical requirement suggests that manual drives are completely compatible for electrical replacement. These aspects of the system are found to be available and well-characterized for shelter cooling.

Because coal has never been used in conjunction with such absorption units, the major area of equipment development will be the design of an appropriate combustion unit. Coal is indicated as the preferred fuel, but the versatility and adaptability of the coal furnace should be investigated for use with other solid fuels such as coke or charcoal. The volume and space requirement of wood will probably not permit it to be a primary stored fuel, but it may be of value in emergencies.

These absorption units will require pre-installation or some means for limited mobility, e.g. wheeled supports. Assembly for activation appears to be straightforward, provided suitable lines

and connections are included. The separation of the motor functions for use with an alternate manual drive, for example the OCD-MRD bicycle drive, seems entirely feasible. If additional bicycle drive capacity is provided, perhaps with electrical storage facilities, no reliance on thermoelectric generation or other electrical source will be needed. The instrumental electrical requirement can be reduced even further for this purpose; for example, relay and solenoid operated fuel valves are not necessary with coal-fired systems.

V. CONCLUSIONS

1. The apparently optimum commercially available aqueous ammonia absorption system can be modified to use coal and other solid fuels instead of natural gas or fuel oil.
2. Shelter heat and rejected heat can be transferred conveniently in shelter systems with finned tube coils which are available and the performance of which is well defined.
3. Complete independence of external electrical sources can be achieved with the OCD-MRD bicycle drive units.
4. Lithium bromide absorption systems are limited to shelter situations in which adequate quantities of cooling water can be provided.

VI. RECOMMENDATIONS

As a result of this study, a coal-fired aqueous ammonia system appears to be of value for shelter cooling. Two specific areas must be studied in greater depth to determine the potential of these systems for shelter use.

The design, construction, and evaluation of a coal furnace for use with such an absorption unit is recommended as the most important area for further work. This work may be either as a separate furnace evaluated with a synthetic thermal load, or as part of the actual absorption unit. As a separate furnace, ultimately the final design would be incorporated with the absorption unit for evaluation of the entire system.

The evaluation of the bicycle drive for electrical substitution in the modified unit also seems necessary. The modifications will include instrument and control alterations, manual furnace operation, emergency installation of shelter conditiong coils, etc. This evaluation will probably be conducted during the synthesized emergency operation of the entire system.

VII. ACKNOWLEDGEMENTS

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APPENDIX

Tabulations of Criteria Values

TABLE 1

Components and Total System Cost

System Code No.	Absorption Cooling Unit	Shelter Heat Transfer Uni	Unit for Heat Rejection	Combustion Unit	Solid Fuel	Total Cost	Overall Rank *
11111	$ 900	$190	Air cooled	$60	$30	$1180	1
11112	900	190	condenser	60	50	1200	1
11123	900	190	and absorber	60	100	1250	2
11124	900	190	are included	60	40	1190	1
			in the ab-				
12111	900	300	sorption	60	30	1290	2
12112	900	300	cooling unit.	60	50	1310	3
12123	900	300		60	100	1360	3
12124	900	300		60	40	1300	2
21211	1100	190	Evaporative	60	20	1370	3
21212	1100	190	water cooler	60	50	1400	3
21223	1100	190	is included in	60	70	1420	4
21224	1100	190	the absorption	60	30	1380	3
			cooling unit.				
22211	1100	300	Storage tank	60	20	1480	4
22212	1100	300	for make-up	60	50	1510	4
22223	1100	300	water not	60	70	1530	4
22224	1100	300	included.	60	30	1490	4
33211	785	Included in	$305	60	20	1170	1
33212	785	absorption	305	60	50	1200	1
33223	785	cooling unit.	305	60	70	1220	2
33224	785		305	60	30	1180	1

* Overall Rank: 1 = $1200 or less
2 - $1201 to $1300
3 = $1301 to $1400
4 = Over $1400

TABLE 2

Components and Total System Electrical Requirement

System Code No.	Absorption Cooling Unit	Shelter Heat Transfer Unit	Unit for Heat Rejection	Combustion Unit	Solid Fuel	Total Elect. Requirements	Overall Rank *
11111	600 watts	350 watts	Included in	None	None	950 watts	1
11112	600	350	absorption	None	None	950	1
11123	600	350	cooling unit	None	None	950	1
11124	600	350		None	None	950	1
12111	600 watts	440 watts	Included in	None	None	1040 watts	2
12112	600	440	absorption	None	None	1040	2
12123	600	440	cooling unit	None	None	1040	2
12124	600	440		None	None	1040	2
21211	950 watts	440 watts	Included in	None	None	1390 watts	3
21212	950	440	absorption	None	None	1390	3
21223	950	440	cooling unit	None	None	1390	3
21224	950	440		None	None	1390	3
22211	950 watts	440 watts	Included in	None	None	1390 watts	3
22212	950	440	absorption	None	None	1390	3
22223	950	440	cooling unit	None	None	1390	3
22224	950	440		None	None	1390	3
33211	500 watts	Included in	900 watts	None	None	1400 watts	4
33212	500	absorption	900	None	None	1400	4
33223	500	cooling unit	900	None	None	1400	4
33224	500		900	None	None	1400	4

TABLE 3

Components and Total System Volume

System Code No.	Absorption Cooling Unit	Shelter Heat Transfer Unit	Unit for Heat Rejection	Combustion Unit	Solid Fuel	Total Volume	Overall Rank *
11111	43 cu ft	11.5 cu ft	Included in	13 cu ft	59 cu ft	126 cu ft	1
11112	43	11.5	absorption	13	256	324	4
11123	43	11.5	cooling unit	10	100	165	2
11124	43	11.5		10	133	198	2
12111	43 cu ft	42 cu ft	Included in	13 cu ft	58 cu ft	156 cu ft	2
12112	43	42	absorption	13	256	354	4
12123	43	42	cooling unit	10	100	195	2
12124	43	42		10	133	228	3
21211	103 cu ft	14 cu ft	Included in	13 cu ft	38 cu ft	168 cu ft	2
21212	103	14	absorption	13	256	386	4
21223	103	14	cooling unit	10	70	197	2
21224	103	14		10	100	227	3
22211	103 cu ft	42 cu ft	Included in	13 cu ft	38 cu ft	196 cu ft	2
22212	103	42	absorption	13	256	414	4
22223	103	42	cooling unit	10	70	225	3
22224	103	42		10	100	255	4
33211	62 cu ft	Included in	42 cu ft	13 cu ft	38 cu ft	155 cu ft	2
33212	62	absorption	42	13	256	373	4
33223	62	cooling unit	42	10	70	184	2
33224	62		42	10	100	214	3

* Overall Rank: 1 = 150 cu ft or less
2 = 151 cu ft to 200 cu ft
3 = 201 cu ft to 250 cu ft
4 = 251 cu ft or more

TABLE 4

Components and Total System Weight

System Code No.	Absorption Cooling Unit	Shelter Heat Transfer Unit	Unit for Heat Rejection	Combustion Unit	Solid Fuel	Total Weight	Overall Rank *
11111	780 lb	165 lb (dry)	Included in	200 lb	3,000 lb	4,145 lb	2
11112	780	165	absorption	200	8,000	9,145	4
11123	780	165	cooling unit	200	3,300	4,445	2
11124	780	165		200	4,000	5,145	4
12111	780 lb	350 lb (dry)	Included in	200 lb	3,000 lb	4,330 lb	2
12112	780	350	absorption	200	8,000	9,330	4
12123	780	350	cooling unit	200	3,300	4,630	3
12124	780	350		200	4,000	5,330	4
21211	1,260 lb	165 lb (dry)	Included in	200 lb	2,000 lb	3,625 lb	1
21212	1,260	165	absorption	200	8,000	9,625	4
21223	1,260	165	cooling unit.	200	2,300	3,925	1
21224	1,260	165	Water Storage	200	3,000	4,625	3
			tank not				
22211	1,260 lb	350 lb (dry)	included.	200 lb	2,000 lb	3,810 lb	1
22212	1,260	350		200	8,000	9,810	4
22223	1,260	350		200	2,300	4,110	2
22224	1,260	350		200	3,000	4,810	3
33211	955 lb	Included in	350 lb (dry)	200 lb	2,000 lb	3,505 lb	1
33212	955	Absorption	350	200	8,000	9,505	4
33223	955	Cooling Unit	350	200	2,300	3,805	1
33224	955		350	200	3,000	4,505	3

* Over Rank:
1 = 4,000 lb or less
2 = 4,001 lb to 4,500 lb
3 = 4,501 lb to 5,000 lb
4 = 5,001 lb or more

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13. ABSTRACT A study has been made of various absorption cycle cooling units and associated components which would be required to maintain a habitable atmosphere in certain identified civil defense fall-out shelters, independent of any external energy sources. Of the many criteria which could be applied to these systems, four were selected as the bases for the final evaluation, i.e., cost, electrical requirement, volume and weight. The selected system consists of the aqueous ammonia absorption cycle cooling unit with heat rejection directly to ambient air from finned-tube condenser and absorber. This unit produces chilled water which is circulated through a finned-tube conditioning coil within the shelter area. Shelter heat is transferred to the chilled water by blowing shelter air and ventilation air through the conditioning coil. Heat to operate the absorption unit is supplied by combustion gases from a furnace designed to burn a volatile-producing fuel with coal as the preferred fuel. Manual power is applied to pump the chilled water and to circulate shelter air and cooling air. A suitably designed furnace needs to be developed, and the normally gas-fired absorption unit must be adapted to the furnace.

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